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INTRAOCULAR LENSES IN MILITARY AIRCREW

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Introduction

Modern advances in microsurgical procedures performed on the human eye distinctly stand out as one of the most, if not the most, dramatic advances in medical sciences over the last 75 years. Cataract surgery has emerged as one of the most common surgical procedures regardless of surgical subspecialty. Although attempts to "surgically" remove cataractous lenses can literally be traced back for thousands of years, visual rehabilitation postoperatively would not reach its zenith until development of the intraocular lens (IOL).

The human eye has two anatomical chambers: an anterior chamber (AC) filled with aqueous fluid between the cornea and the front surface of the lens and a posterior chamber (PC) behind the iris which contains the lens and vitreous (See Figure 1). An intracapsular cataract extraction (ICCE) involves removing the lens in total including its surrounding capsule. Therefore, an ICCE leaves behind no structural elements to support an intraocular lens (IOL) and involves a forward displacement of vitreous material to fill the space formerly occupied by the lens. This forward vitreous movement accounts for some of the increased risk for retinal detachment following an ICCE. Modern microsurgical advances have allowed removal of cataractous lens fibers from inside its capsular bag leaving the posterior capsular face intact and in place as a barrier to hold back the vitreous and a structural element upon which to place an intraocular lens. This type of procedure is called an

extracapsular cataract extraction (ECCE) and represents the standard technique used around the world today. Keeping the posterior capsule intact prevents a significant movement of the vitreous forward and thereby reduces the risk of retinal detachment afterwards. The space left behind, formerly occupied by the lens, will be occupied by aqueous and provides the ideal location for an intraocular lens at the precise focal plane of the natural lens. An individual who does not have an IOL implanted is referred to as being *aphakic* while someone having an IOL implanted is regarded to be *pseudophakic*. Intraocular lenses can be implanted into either the anterior or posterior chambers, although by far the more common location today is in the posterior chamber (See Figure 2).

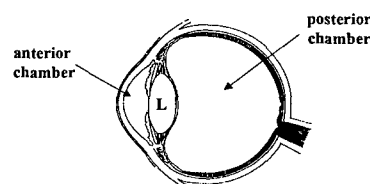


Figure 1: Chambers of the Eye

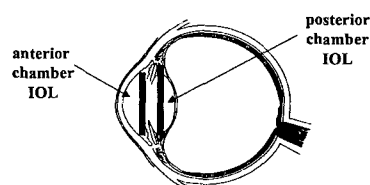


Figure 2: Potential IOL Location Planes

Spectacle eyewear following cataract surgery provided reasonable visual rehabilitation at the time, but the visual side

effects from these very thick spectacles proved very challenging and limiting. With the development of contact lenses, both hard and soft, many of the undesirable optical consequences of thick spectacle lenses were greatly ameliorated. Contact lenses came much closer to replicating the natural optical state of the eye. However, these devices also suffered from some undesirable optical side effects, but in the aged, handling of these small, fragile devices proved a more significant impediment within the population most likely to require such surgery. Younger individuals, suffering from congenital, metabolic, or more typically, post traumatic cataracts, more easily adapted to contact lenses in most applications and environments.

However, the rigors and demands of certain vocational and occupational career fields, such as aviation, continued to pose complex challenges with even these highly successful optical appliances. The operational spectrum associated with modern military aviation environments, such as G forces, altitude and low humidity, coupled with unique and often hostile environmental extremes, posed a subset of problems that not even contact lenses completely solved. In addition, the critical visual demands of aircrew quickly identified a specialized subset that would benefit from reestablishing postoperative image quality that was as close as possible as those originally associated with the natural human lens. Consequently, development of a permanent optical device, an intraocular lens (IOL), that could be implanted within the eye itself as near as possible to the natural optical center of the eye's original lens, offered the greatest prospect to reestablish useful vision to as optically normal as possible. Today these tiny optical devices stand out within the world of ophthalmology, if not all of medicine, as probably the most singularly distinctive medical development of the last

75 years! But, intraocular lenses are more than just a development of a medical device; it is an ophthalmology story deeply rooted in aviation history itself.

Prior to the advent of contact lenses and intraocular lenses, the development of a cataract usually meant the functional end to a military aviator's active flying career. Thick aphakic spectacles induced image size variations between the two eyes that disrupted fusion and prevented stereopsis. Other disadvantages associated with such spectacles included their weight, which resulted in displacement under high $+G_z$, visual field size reductions, visual distortions, ring scotomas, and image magnification, all of which often led to significant perceptual problems. Therefore, prior to 1967, military aviators with advanced cataracts that significantly interfered with vision or aphakia, were grounded and no longer allowed to fly in military aircraft.

The use of contact lenses represented a major improvement in the optical correction of aphakia and an upturn in fortune for aviators. In 1967, the first aphakic USAF aircrew member was returned to limited flying duties following successful cataract extraction that was optically corrected with a hard contact lens.

Although, hard contact lens solved many of the optical and visual problems encountered with aphakic spectacles, including normalization of stereopsis, such lenses are susceptible to displacement under G loading due to their thickness and relative increased weight. Soon thereafter, the advent of soft contact lens materials ameliorated the G displacement problem and became the primary means for optical correction after cataract surgery until the mid 1970's.

In 1979, the first USAF aviator was returned back to flying duties following a successful ICCE extracapsular and insertion of an anterior chamber intraocular lens. The decision to return this aviator to the cockpit was largely predicated on earlier research studies performed by the Ophthalmology Branch of the USAF School of Aerospace Medicine on rhesus monkeys who previously had had a variety of intraocular lenses implanted either into the anterior or posterior chamber of both eyes. After a suitable healing period (6 months), these monkeys were subjected to centrifuge rides up to $+12G_z$. Post-centrifuge slit lamp examinations failed to show any hemorrhages, displacement or dislocation of their intraocular lenses. The stability of tissue fixated IOLs under such G exposures demonstrated by this study resulted in a favorable waiver recommendation for such pseudophakic aircrew, providing other visual performance capabilities, such as visual acuity and stereopsis, met acceptable standards.

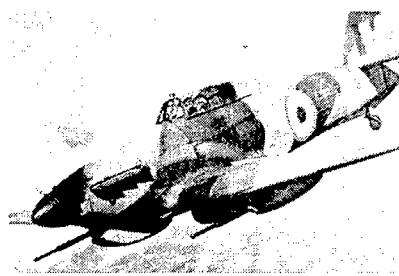
However, the road that finally culminated in these advanced aeromedical studies had its beginnings many years prior and was largely based on the clinical acumen of a single post-World War II ophthalmologist. In November of 1949, Dr. Harold Ridley, a British Ophthalmologist, inserted the first successful human IOL (See Figure 5).

Figure 3:



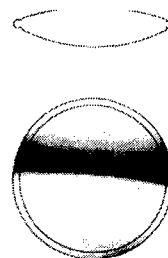
That first IOL was composed of Perspex CQ, polymethylmethacrylate (PMMA), a material that was identical to that used at the time in canopies and windscreens of common British WWII fighter aircraft, such as the Hurricane and Spitfire.

Figure 4:



Dr. Ridley had clinically managed and followed a number of British aircrew members who had sustained penetrating intraocular foreign bodies composed of canopy fragments received during combat. He was impressed with how stable and inert this material was regardless of where the fragment finally ended up resting in the eye. Dr. Ridley also considered another material at the time, glass, which was also a traditional well-known biologically inert material. This first IOL was a thick, round lens without fixation arms fabricated from a Perspex CQ button (See Figure 5).

Figure 5:

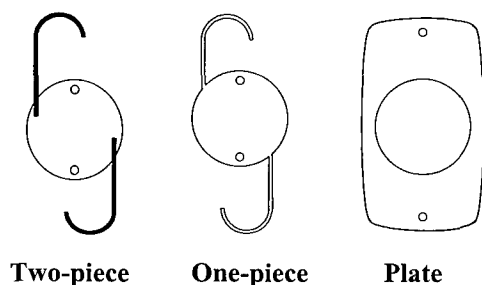


He surgically placed the lens into the posterior chamber on top of the vitreous face following an ICCE close to the plane of the natural human lens. He had previously concluded that the posterior chamber location would allow for the most natural

optics postoperatively. Unfortunately, the lack of fixation arms or haptics to anchor the lens at its location site by inducing fibrotic tissue reaction to fixate it and the fact that his first IOL was very thick and heavy, resulted in the lens displacing out of position and back into the vitreal cavity of the eye. Severe international professional criticism at the time from his colleagues suppressed further advances of the technology for nearly 30 years.

It wasn't until the early 1970's when a resurgence of interest in intraocular lenses reemerged. Intraocular lenses then developed rapidly and passed through considerable transitional alterations that witnessed their preferred insertion site within the eye moved from being clipped to the iris, to the anterior chamber, and then ultimately, and ironically, to the present preferred the plane of choice, namely within the residual capsular bag at the precise planer location of the natural human lens previously concluded to be the ideal site by Dr. Ridley. However, modern posterior chamber IOLs are extremely light in weight and usually have two polypropylene, polyethylene, or PMMA fixation arms, called haptics, to facilitate fixation and to secure them permanently in place (See Figure 6).

Figure 6: Basic Types of IOLs



Subjects

In 1979, a special USAF Aircrew Intraocular Lens Study Group was established at the Ophthalmology Branch of USAFSAM to evaluate and manage these aircrew for the duration of their careers. As of 1 July 1999, the USAF has 65 male aircrew members enrolled in this study, 44 from Active Duty and 21 from the Air Force Reserve (AFR) and Air National Guard (ANG). These 65 aircrew members have had cataract extractions, either ICCE or ECCE, with insertion of IOLs in a total of 80 eyes. Their overall mean age at the time of cataract surgery was 44 years. Active duty pilots ranged in age from 28-64, but on average were 43 years of age, while the AFR and ANG aviators were on average 45 years of age, with a range of 25-60 years.

Intraocular lenses were implanted into the anterior chambers in 4 eyes (5%) and into the posterior chamber in 76 eyes (95%). The IOLs were implanted only into the right eye in 27 (34%), left eye in 23 (28%) and bilaterally in 15 (38%). Of the total 80 eyes, 3 eyes had undergone ICCE (4%) while the vast majority of the eyes, 77 eyes (96%) had ECCE.

Of the 65 total aircrew members, 43 (66%) were pilots, 7 (11%) were navigators, 7(11%) were flight surgeons, and 8 (12%) occupied other ancillary crew positions.

The total accumulated flying hours for the pilots at the time of the surgery was 186,950 hours and individually ranged from a low of 1,000 hours to a high of 9,750 hours. Total flying hours for the navigators was 24,700 hours, with a range between 2,000 and 7,700 hours. Of the pilots, the type of aircraft category flown at the time of the surgery were: fighter-attack-reconnaissance (FAR) in 40%, tanker-transport-bomber (TTB) in 51%, and rotary wing in 9%.

Fifteen of the aircrew had bilateral IOLs: 6 pilots, 2 navigators, 4 flight surgeons, and 3 other crewmembers. Of the pilots with bilateral IOLs, 3 were in fighter aircraft, (T-33, F-15, F16, F-111F), 2 were in tanker-transport-bombers, and 1 in rotary wing aircraft.

The longest follow-up within the IOL Study Group has been for 12 years so far. As best that could be determined, the etiologies of the cataracts in USAF aircrew were: trauma in 17 (26%), associated with the family history of cataracts in 13 (20%), both trauma and family history in 3 (5%), associated with specific ocular cataract syndromes in 2 (3%), but could not be determined in 30 (46%).

Results

Seventy-eight eyes (97%) attained best-corrected visual acuity of at least 20/20 postoperatively and 62 eyes (77%) attained best-corrected visual acuities of 20/15. One pilot suffered traumatic retinopathy at the same time of his cataract and was only able to achieve a best-corrected postoperative visual acuity of 20/50. One pararescue technician also had an associated traumatic retinopathy with a best-corrected visual acuity of 20/40.

Sixty flyers (92%) passed stereopsis testing postoperatively, while 5 flyers (8%) failed stereopsis testing after surgery. Of those 5 flyers, 2 had preexisting microtropia and strabismus, 1 suffered traumatic pupillary dilatation (mydriasis) and also had an epiretinal membrane, 1 had a prior history of central serous chorioretinopathy which had caused a preoperative decrease in stereopsis, and 1 had an unexplained deterioration in stereopsis. Therefore, only 2 aviators appeared to have suffered a degradation in stereopsis after surgery.

Sixty-three flyers (97%) passed red-green color vision testing, while 2 flyers (3%) failed color vision testing postoperatively. Of those 2 flyers, 1 suffered traumatic cataract associated with an epiretinal membrane and 1 had a long-standing history of congenital red-green color deficiency.

We have had no IOL dislocations secondary to exposures related to the aerospace environment. But, we have had a dislocation of an IOL in one aviator postoperatively in a secondary implant (inserted as a second surgical procedure later after the initial cataract extraction) which dislocated slightly following sports trauma. The IOL movement was lateral and did not require surgical repositioning and he was eventually returned back to flying status although restricted from high-performance aircraft.

Aeromedical Recommendations

Fifty-nine out of 65 aircrew members (90%) initially received waiver recommendations and were ultimately waived to return to flying. However, three flyers were grounded for ocular reasons: one was a flight surgeon who developed a retinal detachment following cataract surgery, one was a pilot with diminished stereopsis and visual acuity secondary to formation of an epiretinal membrane over his macula, and one was an ancillary crewmember who had longstanding substandard stereopsis and amblyopia. Three other flyers were grounded for non-ocular reasons that had developed concurrently with their ophthalmic condition: two pilots developed significant cardiopulmonary disease and one developed cardiovascular disease that prevented a favorable waiver recommendation in these crewmembers.

Surgical Recommendations for Aircrew

The current microsurgical procedure of choice in aircrew to remove a cataractous lens should involve an extracapsular lens extraction and the insertion of a unifocal posterior chamber IOL. Whether to use phacoemulsification or suture versus sutureless techniques remain discretionary and individual surgeon decisions. The aim of the modern technique is to preserve the posterior lens capsule intact to allow support for insertion of the IOL into this capsular bag at the original plane of the natural lens. Should intraoperative complications occur, it is still possible for an anterior chamber IOL to be used and still salvage vision and the aviator's career.

The type of IOL to be inserted should involve a one piece PMMA lenticule, with haptics made of either polypropylene, polyethylene, or PMMA. These haptic materials are known to induce local tissue reaction that permanently fixes the IOL in place, a critical requirement for high performance flying. The size of the lenticule should be between 6-7 mm and positioning holes should be avoided if possible. The IOL material should contain UV blocking agents to protect the retina from UV and blue light phototoxicity after the natural lens has been removed. Multifocal lenses should not be allowed because of the overall degradation in visual quality associated with the relative blurring induced by such lenses.

Newer intraocular lens materials, such as silicone and acrylic lens, are also acceptable providing they are not the one-piece variety. Thus, silicone and acrylic lenses with either polyethylene, polypropylene, or PMMA haptics are acceptable since these haptics induce tissue reactions that will fixate these lenses adequately in place as well. However, one-piece (plate) silicone and acrylic lenses are relatively tissue inert

materials that insight little to no tissue reaction in and of themselves. Clinical experience indicates that such lenses can spontaneously rotate and surgeons familiar with these materials can attest to the fact that these lenses can be removed easily from inside the posterior chamber, many years following original insertion because of this relative tissue inertness. The inability of these lenses to tissue fixate represent a contraindication for these materials in aircrew who are likely to experience vibrational and accelerative force extremes. However, it is also possible that in non-high performance aircraft, even the one-piece lens type may be considered, providing that such aircrew would not be eligible for more aggressive aircraft later on in their flying careers.

Following cataract extraction and IOL implantation, since the natural final UV filter, the lens, has been removed, it is extremely important that aircrew continue to be protected from phototoxic exposure for the duration of their flying careers. For this reason, aircrew should be fitted with additional UV blocking eyewear, i.e., UV 400 or similar, and should consider use of appropriate headgear to minimize sunlight exposure.

Aircrew who develop a cataract that requires extraction, should not be considered for return to the cockpit without comprehensive ophthalmological evaluation. They should be at least three months postoperatively, be stable clinically, and have stabilized refractions. All aircrew should be followed on an annual basis to ensure that they continue to meet standards and do not develop known post-cataract surgery complications.

Conclusion

By the creation of the USAF Aircrew Intraocular Lens Study Group, the USAF has accumulated a considerable amount of experience in the management of aircrew in all crew positions and in all aircraft types, following successful cataract surgery and implantation of intraocular lenses. Because such eyes have an increased risk for the development of other postoperative complications, such as retinal detachment, capsular opacification, membranes, and maculopathies, it is necessary that active aircrew members be reevaluated frequently to ensure that their visual performance remains compatible with acceptable vision standards and that no other complications arise that would be incompatible with flying safety and mission effectiveness.

We believe that this has been a highly successful program that has salvaged a considerable amount of aviation experience and has allowed valuable aircrew resources to return to the cockpit. Aircrew members in the Study Group have gone on to accumulate an additional 16,500 flying hours following their cataract extraction and IOL implantation. This figure signifies tremendous savings in both experience and training investments. To date, there have been no mishaps or accidents related to USAF aircrew with IOLs.

IOLs and their ability to correct the optical sequelae induced by removing the human lens remain one of the most notable medical achievements of our time. To fully appreciate the benefits of these appliances, one must consider that in our population, military aviators with very costly training and specialized skills have been fully rehabilitated and returned to the cockpit to fly our fastest and most complex aircraft.

Thanks to Dr. Harold Ridley, and many additional contributors along the way, microsurgical techniques and intraocular lenses have improved to the level where overall success rates, even to standards required in aircrew, remain quite high in competent hands. Almost poetically, nearly 50 years later, Dr. Harold Ridley finally received the international recognition he deserved from his colleagues for his outstanding contributions, not only to the visual rehabilitation of the civilian population, but as the USAF experience illustrates, preservation of valuable aviation resources and flying careers.

Thanks to the tremendous foresight of Dr. Harold Ridley, cataracts may no longer represent an irreversible career-ending development in an aircrew member. The use of modern IOLs has allowed over 90% of those aircrew members who have had cataract surgery to be returned back to the cockpit to a full military flying career. Today, IOLs have also even now found themselves successfully implanted into a NASA astronaut.